ELECTROSTATICALLY CHARGED AEROSOL FILTERS

by

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Introduction

It is recognized that electrostatic forces may represent a significant factor in the filtration of aerosols but comparatively little attention has been given to this aspect of the problem.

Electrostatically charged filters are those in which aerosol removal is accomplished in part by electrostatic forces from fields naturally occurring within the fiber mass. By contrast, in electrostatic precipitators, separation is accomplished by means of electrical power supplied by external electrical apparatus.

Much of current knowledge on electrostatically charged filters is related to the resin-wool filter, a product of European research and development, notably by the British Experiment Station at Porton. It was found that the addition of resin powder to a permeable wool pad would transform it into a highly efficient smoke filter without appreciable effect on resistance. Subsequent research led to the conclusion that improved performance was due to superimposition of electrical forces on the other removal forces normally associated with fibrous filters.

Mechanisms for Producing Static Electrification

Methods which are of most interest in the study of aerosol filters are as follows[1]:

(1) Contact or Volta electrification can occur between clean dry metallic surfaces or between the surface of a metal and a semi-conductor.

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(2) Spray electrification is the production of charge as a result of disruption of liquid surfaces such as by atomization, bubbling of liquids or shattering of high energy liquid jets by solid surfaces.

(3) Frictional or tribo-electrical charging is the most frequently observed mechanism of electrification, and paradoxically the most obscure. This charge is created when two materials are brought into intimate contact and then separated.

Mechanisms of Charge Reduction

Electrostatic charge can be dissipated in several ways[2]:

(1) Grounding. Direct leakage to ground by means of solid conductors (such as metallic strips or wires) or through the medium of a conducting gas.

(2) Humidification. In atmospheres high in humidity a thin film of water vapor collects on solid surfaces. Although pure water is not a good conductor, water in equilibrium with atmosphere contains CO_2 or other air-borne impurities such as salts. This plus the contaminants normally existing on solid surfaces provides a conducting film which permits the charge on the object to leak to ground.

(3) Chemical Agents. There are a large number of antistatic compounds which may be applied to surfaces on which undesirable or dangerous levels of charge may accumulate. Many antistatic agents function by adsorbing a greater than normal conducting film of water onto the charged surface.

(4) Charge Neutralization by Ionization. Ions produced in various ways either by thermal and electrical means or by ionizing radiations are attracted to a charged body and neutralize it.

Measurement of Charge

The gold leaf electroscope is the basic instrument for measuring static electricity. Mutual repulsion of like charges induced on the leaves causes them to diverge in proportion to the amount of charge at the terminal. Readings are only semi-quantitative, however. More precise instruments include fiber electrometers in which the gold leaves are replaced by a quartz fiber suspension. One type, the Lindemann-Ryerson Electrometer, which we use in our laboratory can indicate potentials as small as one hundredth of a volt.

The operation of the usual type of voltmeter requires an appreciable and sustained flow of current which seriously affects, if not completely dissipates, the charge to be measured. There are a few suitable commercial electrostatic voltmeters available which satisfy our requirements. We use a Rawson electrostatic voltmeter in our laboratory for high voltages and have found it light weight and rugged. It has a direct-reading scale and low current drain. To calculate charge, the capacitance of the entire system must be known, so an accurate instrument for making extremely low capacitance measurements is required.

Resin Wool Filter

There is evidence to indicate that Hansen selected calophony resin to powder his wood pads because he sought to add to the filter miniature electrets for attracting aerosol particles(3).

The mode of action and electrical structure of these filters was reported by the British Experiment Station at Porton(4) to be as follows:

(1) The high efficiency of resin-wool filters is due to the attraction of aerosol particles to resin particles covering the fibers.

(2) This attraction arises from electrostatic forces existing in the field between the fiber and the charged resin particles.

(3) The resin particles acquire their charge by friction generated during the manufacturing process.

(4) Although the filter as a whole is electrically neutral, the resin particles are negatively charged and a positively induced charge resides on the wool fibers. The resulting field is non-homogenous

so that uncharged or positively charged aerosol particles are impelled toward the resin.

(5) The long storage life of these filters is attributed to the high electrical resistivity.

(6) Breakdown of these filters is caused by oil mist, carbon smoke and ionizing radiations. These agents remove charge from all good insulators.

(7) High efficiency can be restored by carding or handling. Evidently the resin particles are re-charged by frictional electrification.

(8) Prolonged passage of air or low concentrations of smoke particles through the filter does not increase its efficiency. Apparently, frictional electrification by passage of air and suspended particles through the filter does not occur to any significant degree.

(9) Hansen's idea that the electrical forces were due to the formation of electrets in the filter was discarded following a comprehensive series of tests which failed to support this theory.

Resistivity measurements made at Porton by means of improved apparatus in which the effect of air conduction was eliminated yielded values for resin as high as 10^{21} ohms-cm. Long charge-retention time is correlated with the extremely high resistivity of the resin-wool system, a figure higher than can be measured with present techniques. The possibility of high contact resistance between the resin particles and the fibers may also account for the high charge retention of the impregnant.

Billington and Saunders[5] have shown that with use, there is a gradual drop in efficiency of the resin-wool filter followed by a gradual increase. Resistance varies in a similar manner. Initial high efficiency is due in part to the electrostatic effect, but after this is diminished by gradual loss of charge, plugging comes into play and efficiency begins to increase by the mechanical action of plugging (as in the case of ordinary fiber filters).

As evidence of the fact that improved performance of resin-wool is due to electrostatic forces a filter impregnated with Beckacite (a para-tertiary butyl phenol-formaldehyde modified resin) was exposed to x-rays. Figure 1 from Billington and Saunders(5) indicates that penetration of a methylene blue aerosol increased in proportion to the degree of exposure. From this it may be concluded that ionizing radiations cause diminution of charge on the filter, and consequent decrease in filtering efficiency.

These results were confirmed by tests performed by Thomas(6) in which the passage of tricresyl phosphate smoke through the filter caused a progressive lowering of efficiency. The liquid aerosol was able to wet the fibers and cause the charge to leak off (somewhat the same effect as radiation).

Although initial penetration through a resin-wool filter is low, subsequent low penetration is achieved at the expense of increasing resistance. In industrial applications where the loading is relatively high the resistance increase with time may be so rapid as to seriously shorten the effective life of the filter. The most practical application of resin-wool at the moment therefore, seems to be its use in respirators where filtration velocity and loading are both low.

Current Studies on the Role of Electrostatic Charge in Filtration of Aerosols

The development of new synthetic fibers with good dielectric properties and low moisture regain (making them easily susceptible to static electrification) suggested their possible use in aerosol filtration.

Among the fibers under study are Saran[a], polystyrene, polyethylene, Nylon[b], Dacron[c], Orlon[d], Dynel[e] and Vinyon[f].

a. Vinylidene chloride polymer
b. Polyamid resin
c. Polyester polymer
d. Acrylonitrile polymer
e. Vinylchloride-acrylonitrile co-polymer
f. Vinyl acetate- acrylonitrile co-polymer

Our preliminary activities, of necessity, have been concerned chiefly with selecting methods for filter testing and for measuring electrostatic charge on fibers and aerosols. Evaluating charge on fibers is difficult and a lack of reliable instruments is a serious limitation to research in this field. Equipment has been constructed and standardized and an appreciable amount of preliminary data collected.

In electrostatics, materials generally considered good insulators of current electricity are worthless. For instance, hard rubber, glass, porcelain and bakelite are not adequate for static electricity as they do not provide a high enough degree of insulation. We found it necessary to rebuild some commercial components (generally considered of high quality) with superior dielectrics such as polystyrene and Teflon - which have resistivities of 10^{18} to 10^{21} ohm-cm.

Brush discharge from needle points, sharp edges and other prominences of small radius of curvature was found to be an important source of error in charge measurement. Brush discharge was greatly reduced by "streamlined design" and the use of reduced operating voltages. These measures, with extensive electrical shielding to reduce the effects of stray capacitance and stray electric fields, reduced charge leakage to an acceptable level.

A reliable method for measuring fiber charges utilizes the Faraday effect. With this apparatus, Figure 2, the charge to be measured is placed in a metallic cylinder insulated from ground, and the cylinder, or "Faraday Cage" is connected to an electrostatic voltmeter having a range of 0 to 500 V.

Initial tests were made on 70 micron diameter Saran fibers. A charge could be generated by merely handling the loose fibers briskly after which they were dropped into the Faraday Cage, and the voltmeter read. The mean of ten

g. Tetrafluoroethylene resin

such identical tests was deemed statistically reliable. Knowing the capacitance of all parts of the system the net charge was calculated in terms of microcoulombs per gram of fibers.

Measurements were made with different quantities of fibers to determine the relation of charge to weight. It was found that charge did not increase in proportion to the increase in weight. The relationship between the ratio of charge-to-mass and fiber mass approximated a straight line having a slope of minus 0.3 on log-log paper (Figure 3).

The charge-to-mass ratio on the surface of a sphere having a uniform charge density is a function of the cube root of the mass, i.e. a log-log plot of these variables would have a slope of minus 0.33, a figure remarkably close to our experimentally obtained value. From this, it was concluded that the Faraday Cage measured the net charge residing on the surface of the wad of fibers. This was later confirmed by the observation that the total net charge varies as the square of the radius of the fiber wad.

From the outset it was apparent that atmospheric humidity had an important effect on charge measurements. On days of high humidity the rate of charge leakage from the apparatus was so high as to make it impossible to perform tests. Even moisture from the breath causes a significant discharge. Although it was obvious that control of atmospheric conditions (mainly humidity) in the test area was essential[7], it was not clear what the desirable operating level should be. Over a period of two months we made observations of the rate of leakage of our Rawson meter alone for a variety of dry and wet bulb temperatures. Figure 4, a plot of charge leakage (measured in volts per minute) and humidity, indicates the following:

(1) Leakage is a function of absolute humidity rather than of relative humidity.

(2) Above an absolute humidity of 90 grains per pound of dry air charge

leakage becomes excessive. (This corresponds to a relative humidity of about 58% for a dry bulb temperature of 80°F.). These results are in good agreement with experiences cited in the textile literature in which humidities of 55 to 70% were found to be effective in preventing accumulation of static electricity during the processing of synthetic fibers. By this method the maximum leakage resistance of the meter was found to be 10^{15} ohms. A 150% increase in absolute humidity caused leakage resistance to decrease by a factor of 500, clearly indicating that humidity control is an essential in studies involving electrostatic charge measurements.

Electrostatic Filters

A commercial "self-charging electrostatic filter" consisting of shredded polyethylene sheet was found to have a removal efficiency of 10% based on the National Bureau of Standards discoloration test, and 58% based on the ASHVE weight efficiency test. A comparable ASHVE test of a filter containing a 1/2 inch layer of FG-25 or PF 314 media showed 80% efficiency.

A related investigation is the development of electrostatically charged filters constructed from woven cloth or felt. Since the rubbing of two fabrics causes their electrification, it may be possible to construct a filter of a combination of fabrics which combines mechanical filtration through a cloth medium with precipitation by electrical forces.

A number of synthetic and natural fibers were tested against each other to construct the Tribo-electric series[8] shown in Table 1. Materials are positive to those below them in the series.

A Faraday Cage connected to a Rawson electrostatic voltmeter (Figure 2) was used to make these determinations. A calibrated variable air capacitor was connected in parallel with the voltmeter as a range extender.

A charge of known polarity was placed on the cylinder to obtain a half scale (approximately) meter deflection. Two test samples were vigorously rubbed against each other and one of them dropped into the cylinder. The direction in which the meter needle moved indicated the polarity of the charge on the specimen. This procedure was repeated placing the second specimen in the Faraday Cage, as a check.

An alternate method (used to confirm our results) uses a cathode ray oscilloscope with a direct connection to a beam deflection plate, Figure 5. The upper vertical deflection plate was connected to a Faraday Cage and the procedure followed was similar to that described above. With no sample in the Faraday Cage a spot of light appeared in the center of the screen. If the charged sample caused the spot to move downward it was evident that the specimen was of negative polarity since it caused a repulsion of the electron beam. A positively charged sample produced an upward deflection of the cathode ray.

Based on this information Vinyon, Saran, Dynel and Orlon fabrics were selected as potentially suitable materials for an electrostatic cloth filter, using wool as the charging material. Because of the availability of Orlon, the first filter constructed utilized this fabric, Figure 6a. Orlon cloth travels over rollers on top and bottom of a Lucite box perforated on two opposite faces. The aerosol passed through the cloth into the box and out through a metal duct emerging from one end. The Orlon belt was electrified by the rubbing of a wool-covered paddle geared to the same drive as the belt.

During early tests it was observed that the exit duct became electrically charged with the same polarity as that of the Orlon belt. Since the duct was not grounded, it was deduced that it was being electrified by aerosol particles negatively charged during passage through the Orlon. It was thought that these particles might be collected by the use of a positively charged filter medium. Accordingly, a two-stage unit, Figures 6a, b and c was constructed in which an Orlon screen charged by a wool-covered windshield wiper blade acts as an ionizing stage. The collection stage which follows consists of a wool belt charged by an Orlon-covered paddle. This combination represents an electrostatic fabric filter analogous in many ways to a commercial two stage, low voltage electrostatic precipitator.

The method used to determine the relative magnitude of the charges on the fabric consisted of an aluminum plate suspended near the fabric face and connected to an electrostatic voltmeter with a range extender. With this arrangement it has been possible to measure potentials as high as 15,000 volts on the fabric.

The effect of humidity on the generation and maintenance of charges on fabrics is under investigation. It was observed that the charge on Orlon is much more slowly generated when the absolute humidity is in the vicinity of 90 grains of moisture per pound of dry air. Wool behaves similarly, and appears to be even more sensitive to humidity changes. We are in the process of determining whether charge dissipation is a function of (a) adsorbed or absorbed moisture, (b) decrease in leakage resistance of the measuring system or filter assembly, or (c) some other factors. Results from efficiency tests indicate some benefits are obtained from charging, and this filtering technique will receive further investigation and development.

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TABLE I

TRIBOELECTRIC SERIES OF SEVERAL FIBERS

Positive End

Glass
Wool
Cotton
Nylon
Dacron
Orlon
Polyethylene
Polystyrene
Dynel
Saran
Vinyon

Negative End

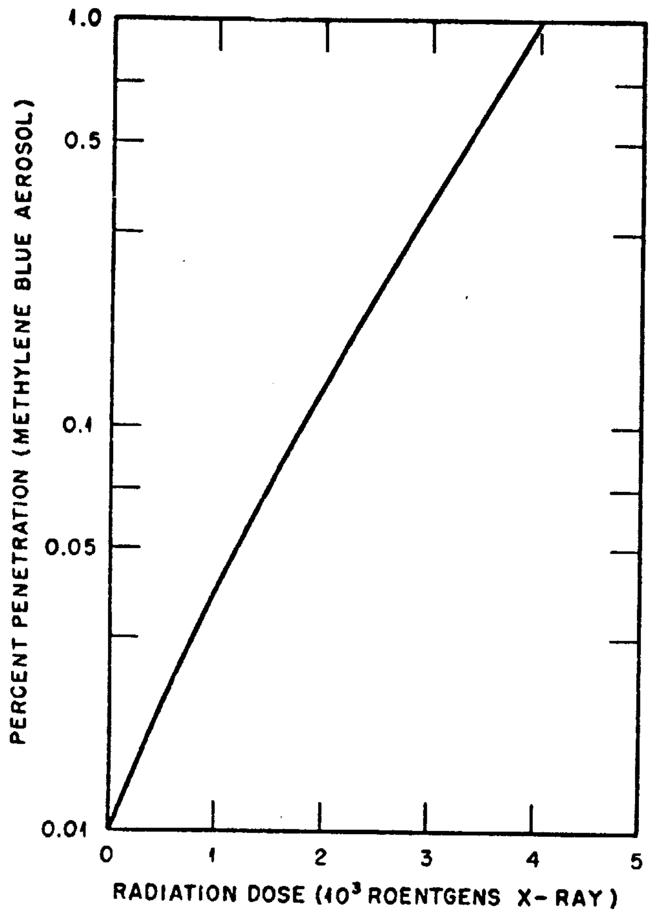


Fig. 1—Effect of radiation on performance of resin-wool filter.

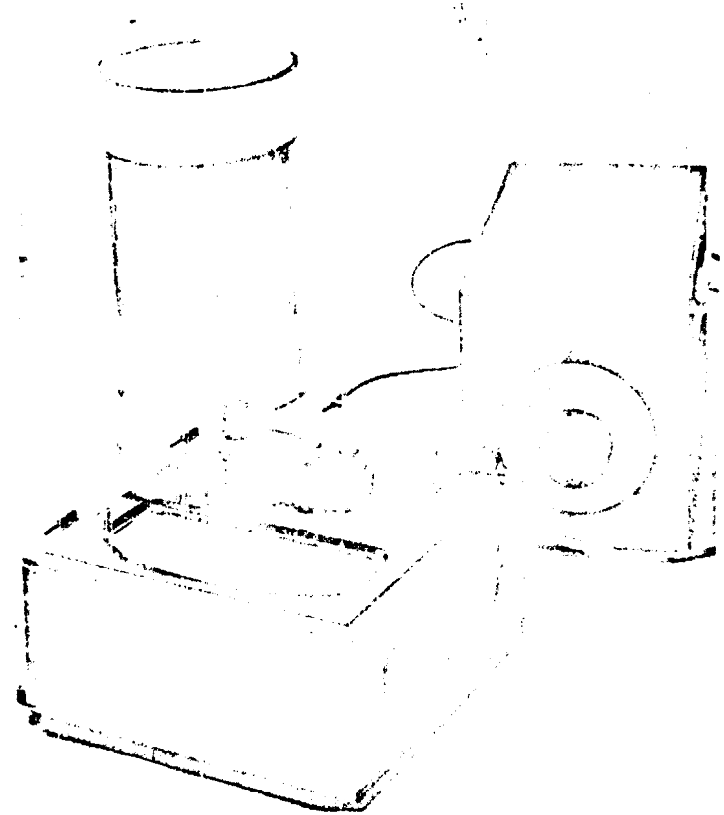


Fig. 2—Apparatus for measuring fiber charge.

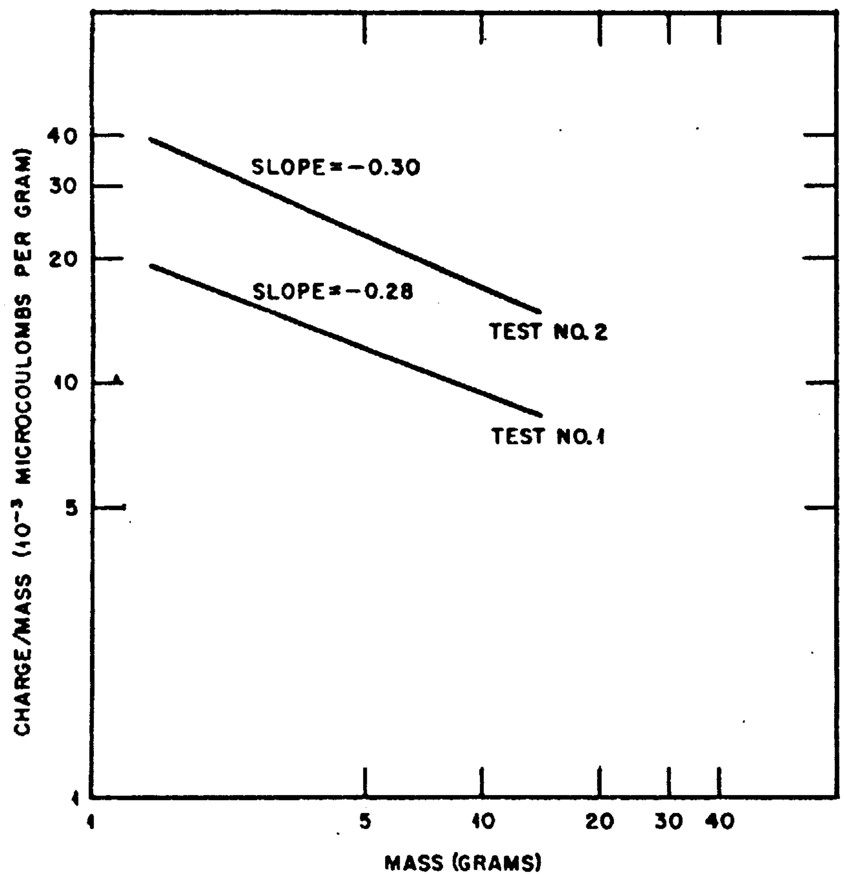


Fig. 3—Relation between charge to mass ratio and mass - saran fibers-70 μ.

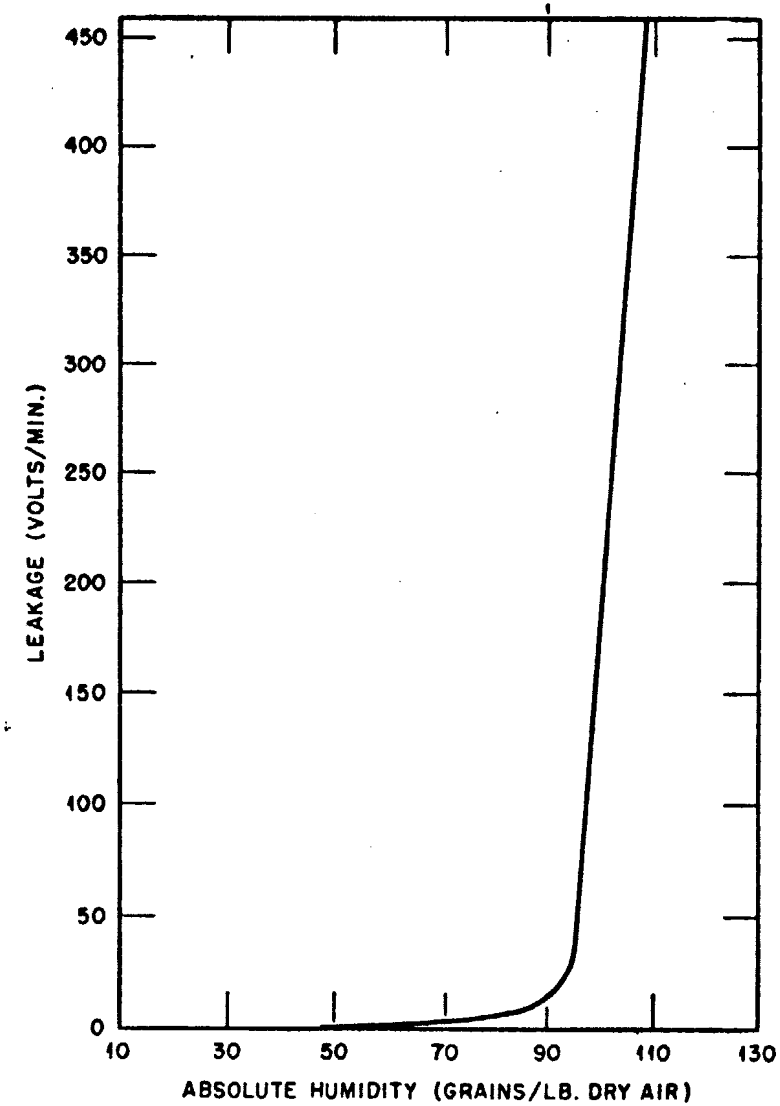


Fig. 4—Effect of atmospheric humidity on charge leakage. Rawson electrostatic voltmeter polystyrene insulation.

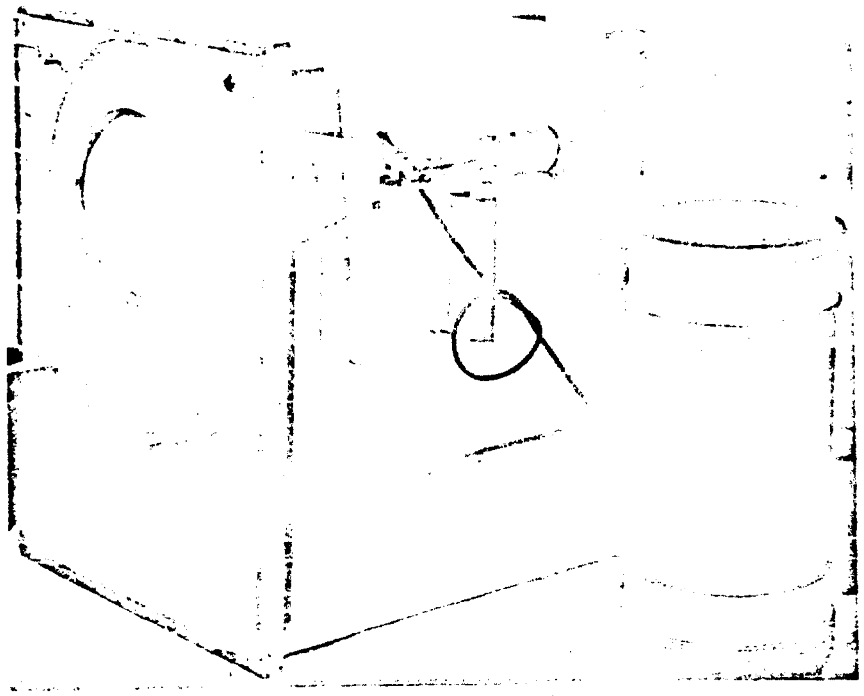
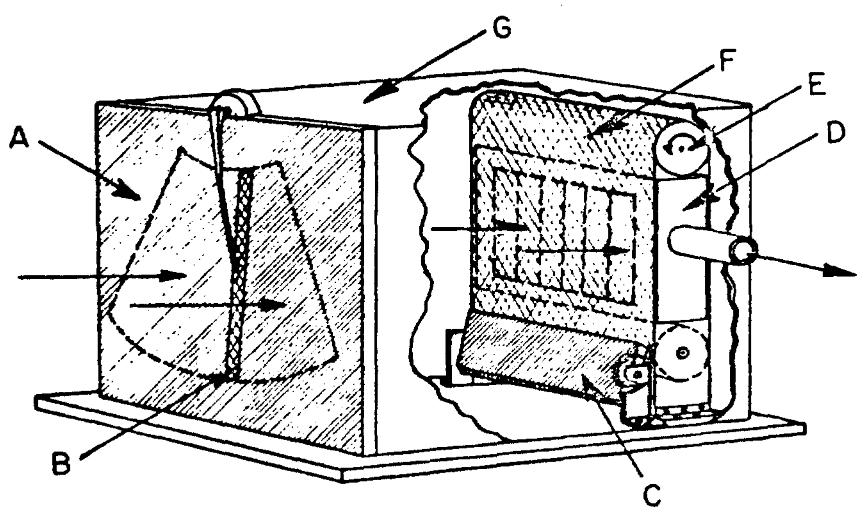


Fig. 5—Oscilliscope for measuring polarity of charge.



A - ORLON SCREEN
B - WOOL COVERED WIPER BLADE
C - ORLON COVERED PADDLE
D - PERFORATED LUCITE BOX
E - LUCITE ROLLER
F - WOOL BELT
G - MASONITE BOX

Fig. 6a—Diagram of electrostatically charged filter.

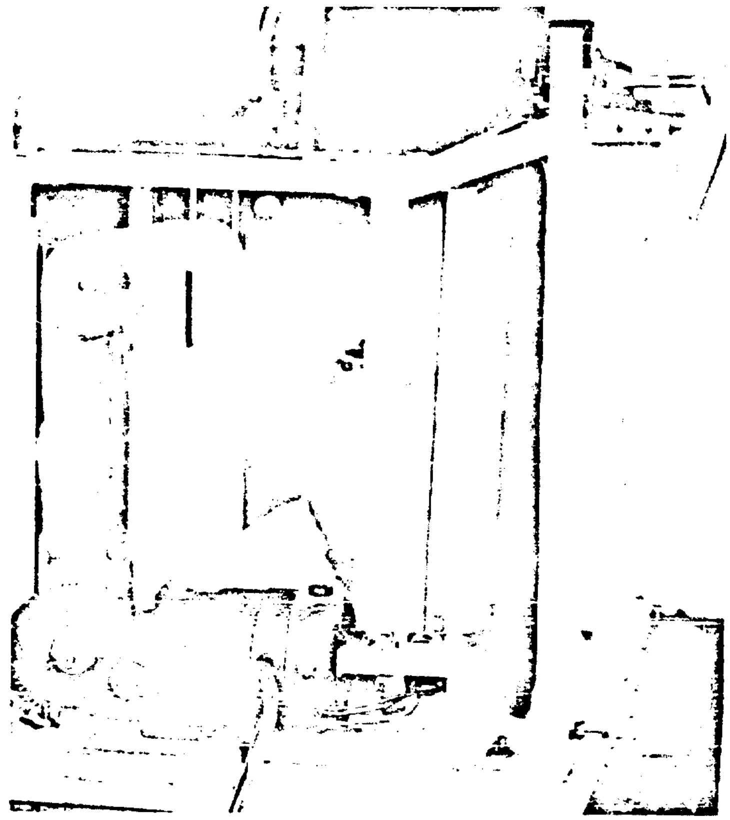


Fig. 6b—Right side of electrostatically charged filter.

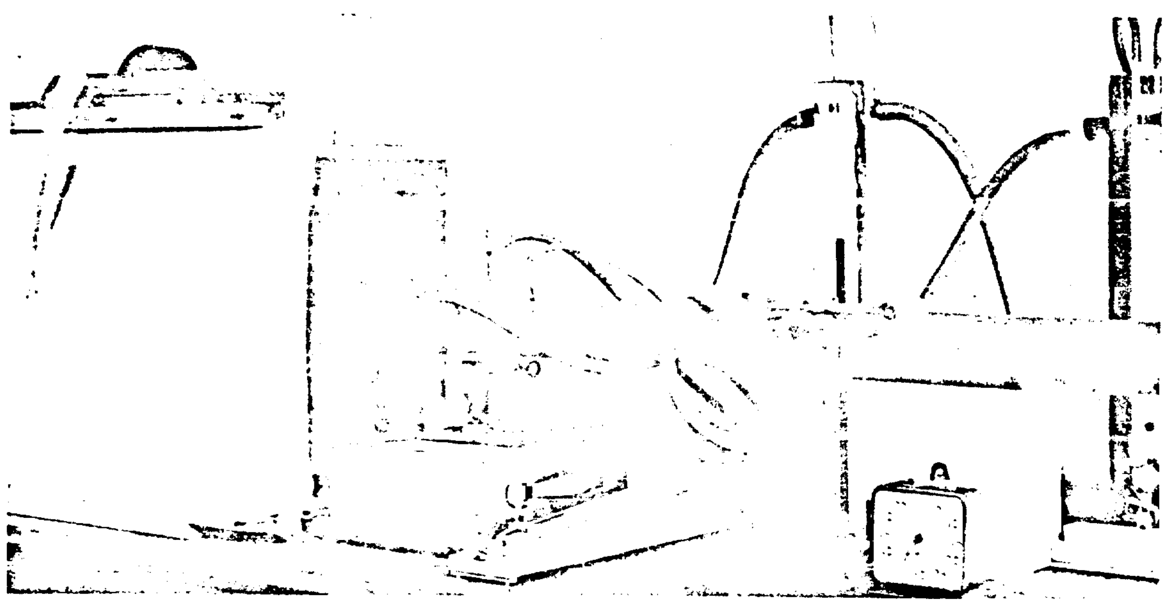


Fig. 6c—Left side of electrostatically charged filter.